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USAF Spatial Disorientation Survey

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SUMMARY

A recent review of mishaps by the Air Force Safety Center (AFSC) determined that spatial disorientation (SD) was implicated in 20.2% of the Class A mishaps in the United States Air Force (USAF) between 1991 and 2000, at a cost of $1.4 billion and 60 lives[8]. However, mishap data only provide limited information about the impact of SD on air operations and, as aircraft losses are relatively infrequent, do not allow detailed analysis of SD by aircraft type. A more thorough understanding of how SD affects aircrew in day-to-day flying would allow appropriate countermeasures to be developed to reduce its impact. A survey was conducted and distributed USAF-wide by flight safety officers. The survey collected data about the incidence of a wide range of SD illusions experienced in the respondents' current aircraft type. Additional information about the most recent SD incident was also collected and analyzed. Data from 2582 completed surveys were analyzed, covering 2.17 million flying hours in 34 currently flown aircraft types. The top three causes of SD for each aircraft stream were: <u>Fast Jet (FJ)</u> – the leans, atmospheric blending of earth and sky, and misjudged position in night formation trail; <u>Multi-Engine (ME)</u> – black-hole approach, sloping horizon, and the leans; <u>Trainer (TR)</u> – the leans, atmospheric blending of earth and sky, and Coriolis illusion; and <u>Rotary-Wing (RW)</u> – undetected drift, misleading altitude cues, and brownout/whiteout. The incidence and severity of SD were related to aircraft stream with FJ and RW pilots being affected most. Overall, 8% of surveyed pilots had experienced a severe episode of SD adversely affecting flight safety. Experienced aircrew, as well as those that had received previous in-flight training, reported more illusions suggesting that these factors helped with recognition of SD in flight. Despite being a regular topic at flight safety briefings, pilots still frequently experience SD sufficient to impair performance. This USAF-wide SD survey identifies problem areas for pilots of different aircraft types, which should allow training and research to be targeted more effectively in future. However, with the advent of helmet-mounted displays, greater use of night vision devices, and increasing aircraft agility/performance, SD related mishaps will continue to pose a significant threat to aircrew. Innovative technological solutions may be required to prevent an increase in SD related mishaps.

INTRODUCTION

Much of what is known about the incidence of SD is derived from published surveys of aircraft mishap data. The SD mishap rate, as a percentage of all aircraft mishaps, has varied widely in these surveys, ranging from 2.5% to 30.8% in different aircrew populations[2-5,12,13,16,18,19,21,22,27-29]. A number of factors are responsible for this wide variation. Firstly, SD mishaps have a high fatality rate and the role that SD may have played in the mishap can often only be inferred from circumstantial evidence. In light of this, mishap Boards of Inquiry have not always been consistent in considering SD as a causal or contributory factor in mishaps. Furthermore, mishap surveys have used a variety of definitions for SD, with profound consequences on the SD-attributable rate[21]. However, few would doubt that SD is a significant flight safety

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issue and, despite a fall in aviation mishap rates overall, recent figures for SD-attributable mishap rates show no significant decrease over the past 3 decades. In the 10-year period between 1991 and 2000, SD was a causal or major contributory factor in 20.2% of USAF Class A mishaps at a cost of $1.4B and 60 aircrew lives[8]. These figures are consistent with recent reports from the US Army and USN that have shown SD to contribute to 27% and 26% of mishaps, respectively, with a fatality rate 3 times that of non-SD accidents[11,15]. However, although mishap surveys have been valuable in raising awareness of SD as a problem in the aviator community, they reveal little about the frequency with which pilots are affected by SD or the effect SD has on their performance.

Previous surveys of the incidence of SD in pilots have frequently been confined to pilots flying a restricted range of aircraft types, while others have only looked at specific types of SD (Table 1). Furthermore, as with the mishap surveys, a variety of definitions of SD have been used, thereby making it difficult to compare the results from one survey with those of another. Over time, changes in flight symbology, aircraft performance, and pilots' SD training may also be expected to have an effect on the incidence of SD, making it difficult to apply the findings of past studies to pilots flying aircraft currently in service.

Author	Years	Survey Group	Comment
Clark (1971)[6]	1970	336 USN, US Army & USAF pilots. All main aircraft types	
Tormes & Guedry (1975)[26]	1974	104 USN helicopter pilots	
Steele-Perkins & Evans (1979)[25]	1978	182 RN helicopter pilots	
Lyons & Simpson (1989)[17]	1986-87	97 USAF tactical aircrew	Survey of giant hand phenomenon only
Kuipers et al (1990)[14]	-	209 RNLAF fighter pilots (NF5 and F16)	
Navathe & Singh (1994)[20]	1989-90	413 Indian Air Force pilots. All main aircraft types	
Durnford (1992)[9]	1991	338 UK Army pilots. Almost exclusively helicopter pilots	
Collins & Harrison (1995)[7]	1992	96 USAF F-15C Desert Storm pilots	Single aircraft type
Braithwaite et al (1998)[4]	1993	299 US Army helicopter pilots	
Sipes & Lessard (2000)[23]	1997-98	141 USAF pilots attending the Advanced Instrument School. All main aircraft types	
Sixsmith (2001)[24]	2001	92 RAF/UK Army pilots. All main aircraft types.	Survey of break-off phenomena (giant hand and detachment) only

Table 1. Surveys of pilots' experiences of SD

This paper describes a USAF-wide questionnaire-based survey of pilots aimed at establishing the current incidence and severity of SD in a wide variety of USAF aircraft types. The questionnaire was developed with the hope that it could be used as a standardized tool that could be used to track changes in the incidence of SD over time and across different aircrew populations. In this way, it could be used to identify the effectiveness of new SD countermeasures.

METHOD

Questionnaire Design and Distribution

A two-page questionnaire based on that used by Sipes and Lessard[23] was developed to collect anonymous data from pilots regarding their experience of SD in their current aircraft types. However, whereas Sipes and Lessard recorded the pilots' total count of various illusions in their two most recent aircraft types, this study looked at the frequency of individual illusions that were being experienced only in the pilots' current aircraft type. Questions addressed pilot characteristics; previous SD training; experience of specific illusions/factors contributing to SD, and details of the pilots' most recent SD incident. The questionnaire was field-tested on 60 students attending the USAF Advanced Instrument School at Randolph AFB, Texas. The questionnaire was subsequently distributed electronically by the US Air Force Safety

Center (AFSC) to all Flight Safety Officers and was administered at a squadron flight safety meeting. In order to get some idea of the response rate, the Flight Safety Officers were asked to coordinate the returns and submit a return rate for their particular squadrons. Questionnaires were completed anonymously.

For the purposes of this survey, a modified version of the Air Standardization Coordinating Committee's Working Party 61 (ASCC WP61) definition of SD was used:

An incorrect perception of linear/angular position, or of motion, relative to the Earth's surface or another aircraft, SUFFICIENT TO AFFECT PERFORMANCE, SITUATIONAL AWARENESS OR WORKLOAD – HOWEVER SLIGHT THAT EFFECT MAY BE.

It was considered desirable to collect data only on SD incidents that had a perceived impact on performance, situational awareness or workload, as these have a potential impact on flight safety and are of concern to aircrew.

For each of the specific illusions/factors listed in the questionnaire, a short description was given in terms that pilots could readily understand, similar to that of Sipes and Lessard[23]. Information about the pilots' most recent SD incident was collected using pick-lists for time since last SD; phase of flight, weather conditions; illumination level; terrain type; visual aids, and severity. There was also a space for the pilot to record a description of the incident, what caused it, and how recovery was carried out. Only time since last SD and severity were analyzed for this paper.

Following presentation of early preliminary results at an ASCC WP61 meeting in November 1999, the survey, with minor modifications, was subsequently adopted as a standardized tool for collecting data on the incidence of SD in flight[1]. Researchers in the UK have recently used this to look at the incidence of SD both in fixed- and rotary-wing aircrew[10].

Between Aug 99 and Jan 00, 2582 questionnaires were returned and their data were entered on an *MS Access* database for analysis. Individual aircraft types were categorized as Fast Jet (FJ), Multi-Engine (ME), Trainer (TR) and Rotary Wing (RW) in order to enable comparisons to be made with data obtained from the survey being conducted on UK aviators using a near-identical questionnaire. The classification of USAF aircraft used in this paper is shown in Table 2.

Aircraft Stream	Aircraft Types
Fast Jet (FJ) (n=468)	A-10 (n=26), F-15 (n=123), F-16 (n=313), F-117 (n=6)
Multi-Engine (ME) (n=662)	B-1 (n=6), B-2 (n=1), B-52 (n=4), C-5 (n=52), C-9 (n=42), KC-10 (n=28), C-12 (n=5), C-17 (n=11), C-20 (n=1), C-21 (n=57), C-130 (n=198), MC-130 (=25), AC-130 (n=23), C-135 (n=6), KC-135 (n=154), RC-135 (n=1), C-141 (n=47), Boeing 737 (n=1)
Trainer (TR) (n=1288)	T-1 (n=147), T-3 (n=1), T-37 (n=750), T-38 (n=336), AT-38 (n=49), BE-40 (n=3), Piper (n=1), Cessna-150 (n=1)
Rotary Wing (RW) (n=101)	HH-60 (n=14), MH-53 (n=26), UH-1 (n=61)
Not Determined (n.=63)	-

Table 2. Classification of USAF aircraft.

The severity of the most recent and worst-ever SD incidents used the same classification as that used by Durnford and Braithwaite in their surveys of SD in helicopter pilots[4,9]:

Minor – Flight safety not at risk
Significant – Flight safety not at risk but could have been jeopardized under different conditions
Severe – Flight safety was at risk

Statistical Analysis

Statistical analysis was performed to investigate the effects of the main independent variables: age, crew position, total hours flown, aircraft type, and hours-on-type. Controlling for these factors, the effects of training frequency, training type, rating of training, and trainer (flight surgeon, physiologist, pilot or other) on the dependent variables were also considered. The factors, factor type, and levels used in the analysis are

listed in Tables 3 and 4. Due to the skewed distribution of the responses towards 'never' and 'rarely', the responses were weighted as follows: 0 for 'never' and 1 for 'rarely or above'.

The dependent variables comprised the frequency of illusions (combined and in separate categories) and the rated severity of the most recent and worst ever SD experience (see Table 5). The display illusions were analyzed together as a group and with HUD-related SD and NVG-related SD on their own. As the miscellaneous illusion category could not be logically grouped together, it was decided to analyze the group as three separate items: giant hand/detachment; SD due to task saturation (distraction), and SD due to poor crew coordination.

Variables	Type	Levels
Age	Covariate	
Crew Position	Factor	Student Pilot, Pilot, Instructor Pilot
Total Hours Flown	Covariate	
Aircraft Stream	Factor	Trainer, Multiengine, Fast-jet, Rotary, Not Specified
Hours-on-type	Covariate	

Table 3. Main independent variables used in the analysis

Variables		Type	Levels
Frequency of training (months)		Factor	<6, 6-12, >12-24, >24-48, >48
Type of training:	In-Flight	Factor	Not Given, Given, Not Specified
	Ground Demo	Factor	Not Given, Given, Not Specified
	Lecture	Factor	Not Given, Given, Not Specified
Rating of training		Covariate	
Trainer		Factor	Flight Surgeon, Physiologist, Pilot, Other

Table 4. Training independent variables used in the analysis

No.	Variables	Type	Levels
1	All illusions	Factor	Principal Component
2	Visual illusions	Factor	Principal Component
3	Nonvisual illusions	Factor	Principal Component
4	Displays illusions	Factor	Principal Component
5	Central psychological (giant hand & detachment)	Factor	No=0, Yes=1
6	Distraction due to task saturation	Factor	No=0, Yes=1
7	Poor crew co-ordination	Factor	No=0, Yes=1
8	HUD illusions	Factor	No=0, Yes=1
9	NVGs illusions	Factor	No=0, Yes=1
10	Severity of most recent SD experience	Factor	Never/minor=0, Significant=1, Severe=5
11	Severity of worst ever SD experience	Factor	Never/minor=0, Significant=1, Severe=5

Table 5. Dependent variables used in the analysis

The dependent variables 1-4 in Table 5 are the results of applying a principal component procedure to obtain a single measure to describe the effect. The natural logarithms of total flying hours and hours-on-type terms were used in the analysis. Variables were selected from the possible combinations (age, crew position, total hours flown, aircraft type, hours-on-type, frequency of training, type of training, rating of training and trainer) by a 'stepwise' method. A multiple analysis of variance was used, with a significance criterion of $p < 0.05$. In cases of significance, post-hoc tests (Scheffe and Bonferroni) were performed to identify the source of any significant effects within each factor.

RESULTS

Although it was not possible to find out how many of the USAF's 12,000+ pilots received a questionnaire, many Flight Safety Officers provided return rate data for their particular squadrons. Of the 2582 responses, 40.7% were returned from squadrons with a return rate >50%, 18.1% came from squadrons with a return rate <50% and squadron return-rate data were not available for 41.2% of responses. There was no significant difference in the reporting of SD between questionnaires from squadrons with a return rate >50% and those from squadrons with a return rate of <50%.

The demographic data showed that respondents' age distribution was similar to that of the USAF pilot cadre in general, but with an over-representation of pilots aged 22-25, corresponding to a high return rate amongst student pilots. The mean age of respondents was 30.9 yrs (sd 6.5 yrs). Overall, pilots recorded a mean total flight time of 1815 hrs (sd 1677 hrs) with 842 hrs (sd 1007 hrs) being spent on their current aircraft types – a total flight time of 2.17M hrs on current type for analysis. Almost all aircraft types were represented, with significant returns from each of the principal aircraft streams (FJ, ME, TR and RW).

Respondents reported receiving some form of SD training, with a mean frequency of 17.6 months (SD = 13.89 mo). Most of this training was provided by physiologists (51.5%), but with pilots also being actively involved (32.9%). Flight Surgeons were not actively involved in SD training, delivering just 2.1% of pilots' most recent SD training. The percentages for previous experience of SD training by lecture, ground demonstration, and in-flight demonstration were 84.7%, 78.7% and 58.3%, respectively. Only 0.3% of pilots could not recall having received any SD training. Data on pilots' previous experiences with SD training showed that pilots were generally happy with the training they had received, with 92.9% of pilots rating their training satisfactory or better (see Fig. 1).

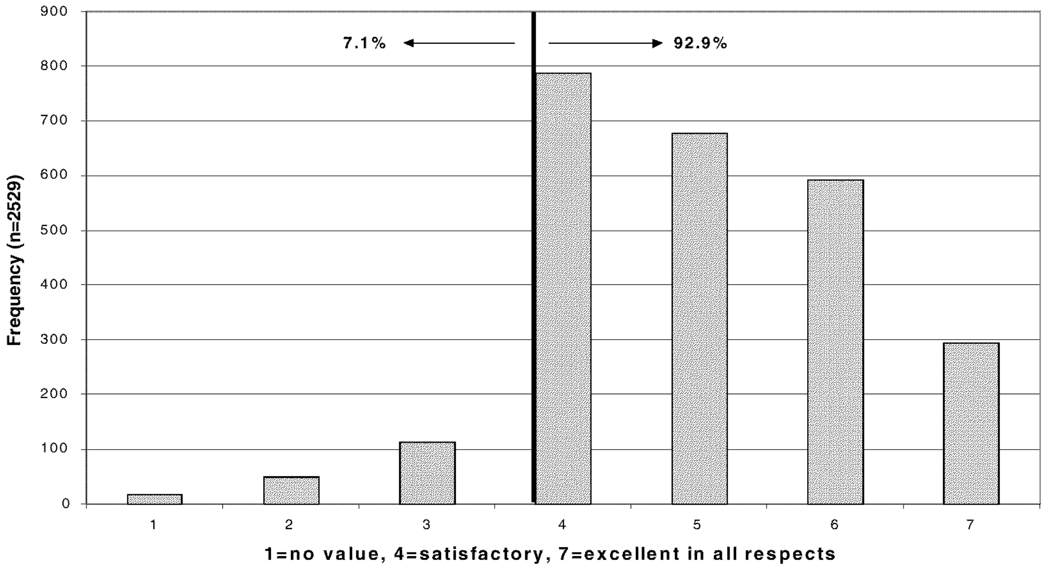

Figure 1. Pilot satisfaction with SD training

The frequency distributions for each of the specific SD illusions described on the questionnaire for all aircraft types are shown in Figs 2-5. The following terms were used to describe frequency: "rarely" (experienced only once or twice in current aircraft type), "seldom" (encountered in <5% of all sorties), "occasional" (<25% of all sorties), and "frequent" (>25% of all sorties).

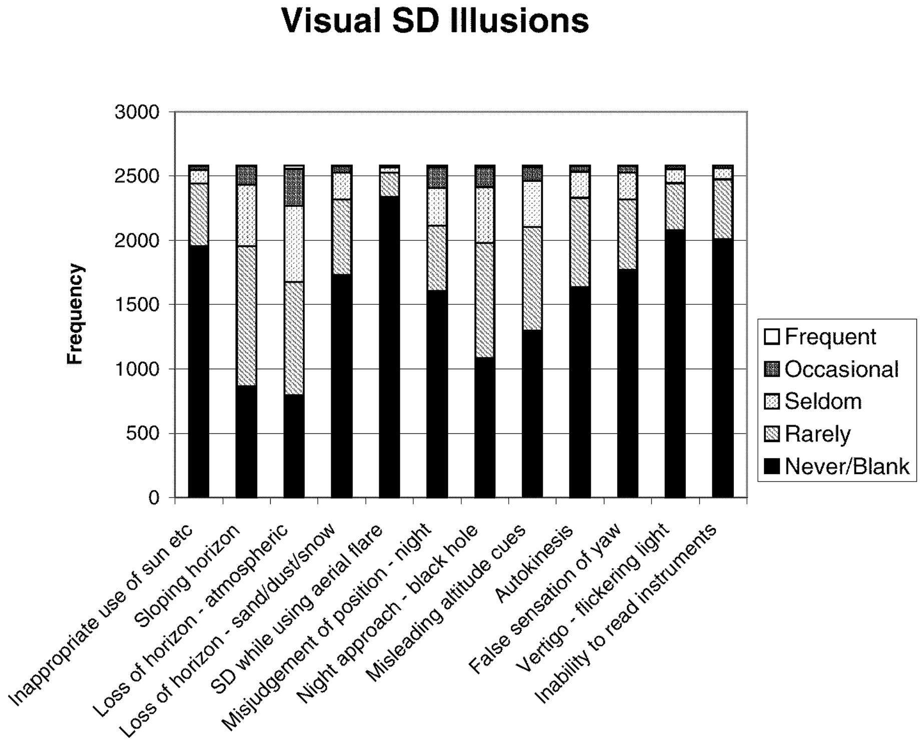

Figure 2. Frequency distribution of visual SD illusions/factors.

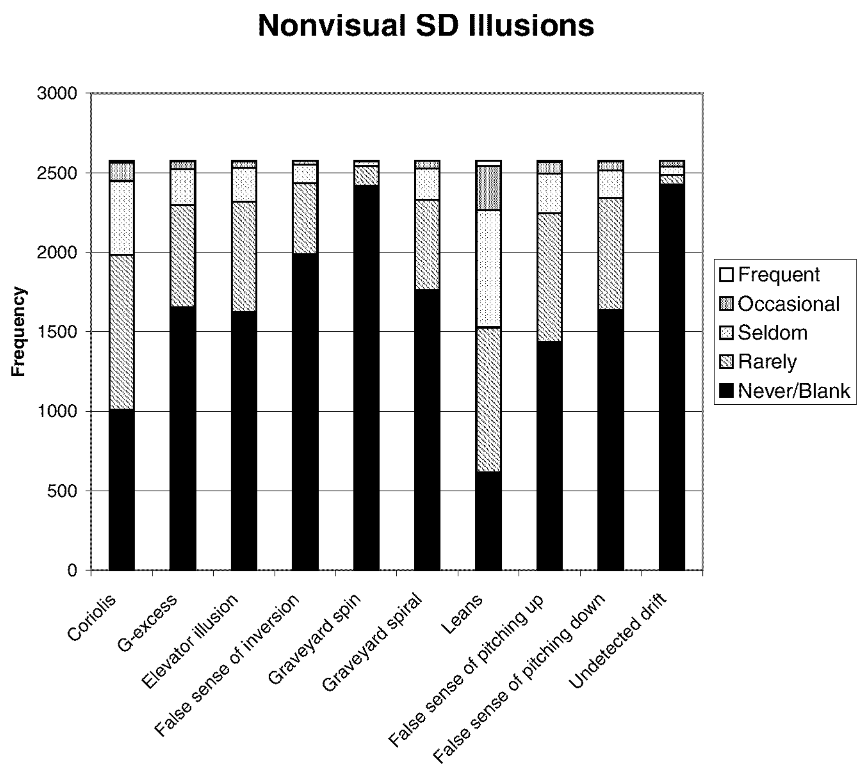

Figure 3. Frequency distribution nonvisual illusions/factors

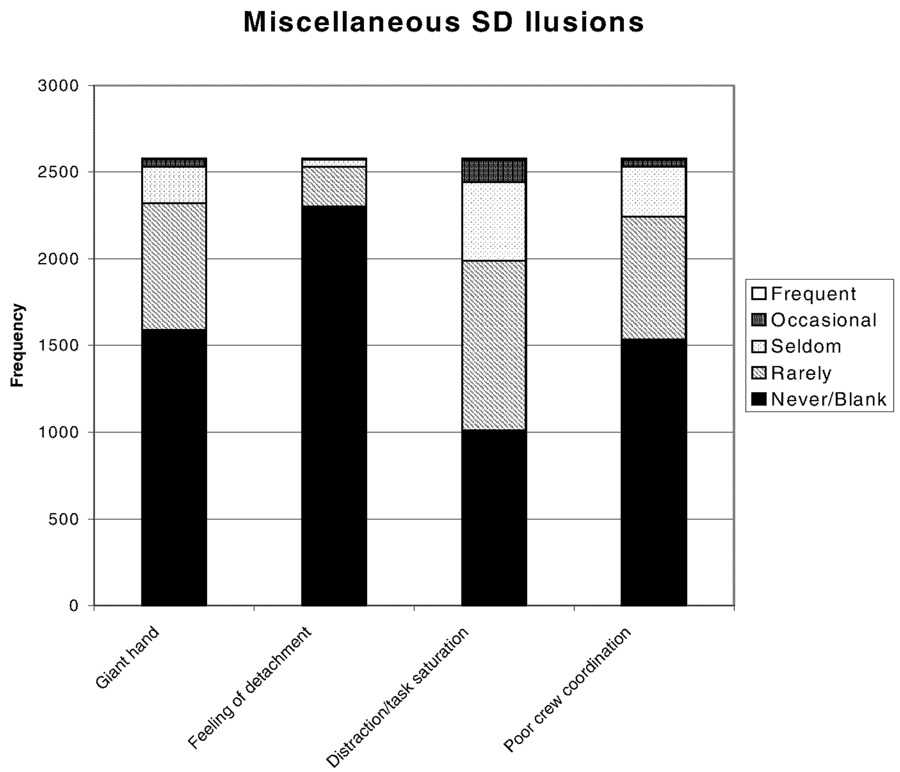

Figure 4. Frequency distribution of miscellaneous SD illusions/factors

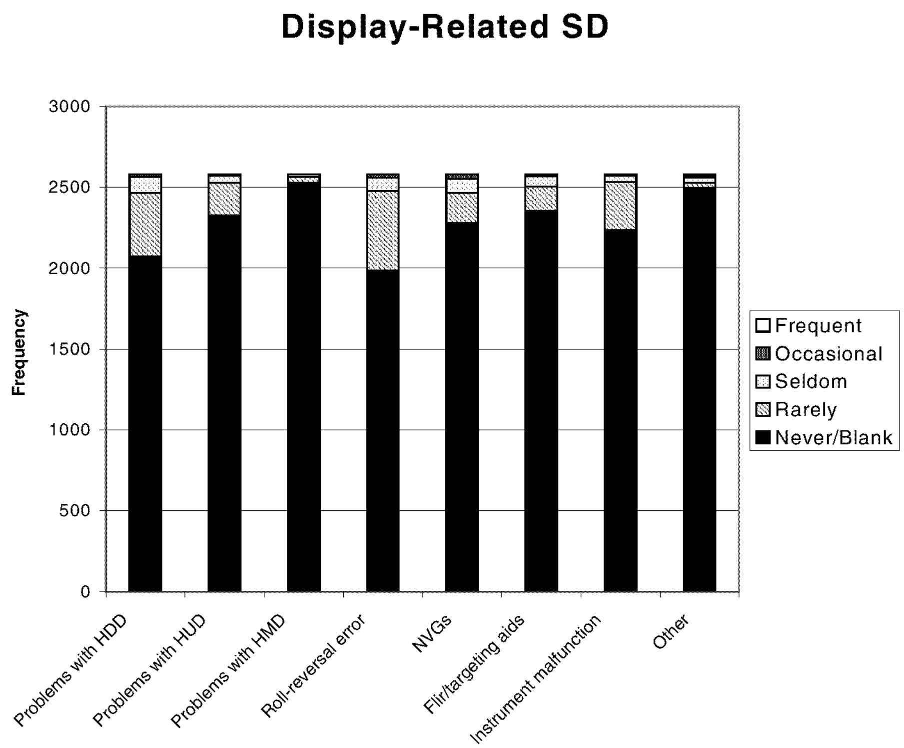

Figure 5. Frequency distribution of display-related SD illusions/factors

On average, pilots reported having experienced 10.6 of the 34 possible SD illusions or situations listed on the questionnaire. Only 6% of pilots reported no episodes of SD in their current aircraft type and most of these were student pilots with limited flying hours. The frequency with which each description of SD was reported, broken down by main aircraft type, is shown at Table 6.

Abbreviated Description (Ranked by % of all pilots reporting SD incident)	% Reporting at least 1 incident				
	All	FJ	ME	TR	RW
Leans	76.0	83.8	74.5	74.5	75.2
Loss of horizon – atmospheric	69.2	78.4	71.9	64.8	66.3
Sloping horizon	66.4	71.6	78.5	58.4	65.3
Coriolis	60.8	62.2	59.4	62.3	42.6
Distraction/task saturation	60.7	64.7	68.2	55.3	60.4
Night approach – black hole	58.1	65.2	82.6	42.4	57.4
Misleading altitude cues	49.8	64.7	58.9	37.2	80.2
False sense of pitching up	44.3	53.4	45.3	42.3	19.8
Poor crew coordination	40.5	18.6	60.9	35.4	68.3
Giant hand	38.4	40.8	37.7	36.5	55.4
Misjudgment of position – night	37.8	75.0	55.2	15.3	37.6
Elevator illusion	37.1	37.0	37.6	37.1	31.7
Autokinesis	36.7	40.8	51.9	25.9	45.5
False sense of pitching down	36.5	47.6	37.0	33.8	17.8
G-Excess	35.9	53.2	21.2	39.4	13.2
Loss of horizon – sand, dust, snow	33.0	41.0	42.8	21.4	76.2
Graveyard spiral	31.7	31.4	31.8	31.3	38.6
False sense of yaw	31.5	38.7	41.6	24.5	25.7
Inappropriate use of sun etc	24.2	35.9	26.0	18.9	22.8
Roll-reversal error	23.0	20.3	21.8	24.2	25.7
False sense of inversion	22.9	27.8	20.0	23.4	12.9
Inability to read instruments	22.1	19.2	18.0	25.8	18.8
Problems interpreting head-down display	19.8	27.8	22.4	14.8	22.8
Flicker vertigo	19.6	22.9	23.3	15.1	36.6
Instrument malfunction	13.4	14.5	14.5	10.9	18.8
SD while using night vision goggles (NVGs)	11.7	13.7	17.6	3.3	72.3
Detachment	10.8	6.6	13.5	10.9	11.9
Problems interpreting head-up display (HUD)	9.9	38.0	3.0	4.0	1.0
SD using aerial flare	9.5	17.7	7.1	7.1	12.9
SD using forward looking infra-red (FLIR)/targeting aids	8.8	24.1	5.6	2.7	32.7
Graveyard spin	6.3	4.3	2.4	9.2	1.0
Undetected drift	5.9	2.4	1.5	3.0	90.1
Other	3.3	5.6	2.7	2.6	3.0
Problems interpreting helmet mounted display (HMD)	2.1	2.8	2.6	1.5	0

Table 6. Rank Order of the Most Frequently Experienced Illusions

Overall, the most frequently encountered visual causes of SD were sloping horizon, atmospheric blending of earth and sky, black-hole approaches, and misleading altitude cues. Similarly, the principal nonvisual types of SD were the leans, the Coriolis illusion and the G-excess illusion. However, the most frequently reported disorienting condition for helicopter pilots was undetected drift (90.1%). Among the miscellaneous illusions/factors, task saturation was the most frequently reported problem. In addition, poor crew coordination and the giant hand phenomenon were experienced by 40.5% and 38.4% of all pilots, respectively. Few pilots reported problems with display- related SD. However, it should be noted that only 22.8% of all pilots responding to this questionnaire had flown with aircraft with head-up displays (HUD) capable of displaying primary flight reference symbology - of these, a much larger percentage (38%) reported problems interpreting spatial orientation information on the HUD. Similarly, only a small percentage (11.2%) of all surveyed pilots reported SD problems with night vision goggles (NVGs), RW pilots were presumably most likely to fly with NVGs and 72.3% of these pilots reported SD while using these devices in flight. Although they are not yet in service, a question regarding helmet-mounted displays

(HMDs) was included in the survey for future use. The small number of pilots reporting problems with HMDs, therefore, erroneously completed that part of the survey. This gives an indication of the error rate that may apply to other illusions (2.1%). A similar error rate of 1.9% was found by looking at reports of undetected drift among non-RW pilots.

Although Figures 2-5 give overall results for all aircraft types combined, Table 6 gives details of the types of illusions being reported most frequently by pilots in each main aircraft stream. The top three illusions for each major aircraft stream were as follows:

FJ: 1) the leans; 2) atmospheric blending of earth and sky; and 3) misjudged position in night formation trail.
ME: 1) black hole approach; 2) sloping horizon; 3) the leans.
TR: 1) the leans; 2) atmospheric blending of earth and sky; and 3) Coriolis illusion
RW: 1) undetected drift; 2) misleading altitude cues; and 3) brownout/whiteout.

Although fixed-wing pilots of all aircraft tended to experience similar illusions, the SD experience of helicopter pilots was found to be fundamentally different.

Additional information was obtained about the respondents' most recent SD incident. 26.9% of pilots had experienced SD in the month prior to the survey, and 58.2% of pilots had experienced SD in the previous six months. Most of these incidents were minor in nature; only 0.7% were judged to be 'severe' and a further 10.6% were considered 'significant'. Pilots were also asked to rate the severity of their worst SD incident in their current aircraft type. Overall, 8.2% of pilots reported having experienced a 'severe' episode of SD and a further 32.3% reporting previous incidents of 'significant' SD. There were large difference based on the pilots' aircraft stream, as shown in Table 7.

	FJ		ME		TR		RW	
	Recent	**Worst**	**Recent**	**Worst**	**Recent**	**Worst**	**Recent**	**Worst**
Minor	72.9%	29.3%	74.1%	32.9%	70.6%	40.1%	61.2%	23.5%
Significant	16.4%	43.1%	10.5%	38.1%	8.1%	25.3%	21.4%	41.8%
Severe	1.6%	14.4%	0.5%	5.8%	0.5%	6.7%	2.0%	19.4%
Not Recorded	9.1%	13.1%	15.0%	23.2%	20.9%	27.9%	15.3%	15.3%

Table 7. Severity of SD incidents by aircraft stream.

Statistical Analysis

Table 8 provides an overview of the results from the statistical analysis of the survey data. As illustrated, it shows that factors that influenced the susceptibility to SD were mainly aircraft type, whether in-flight training had been received, total flying time, and hours-on-type. Crew position, ground-based training, and which professional type provided the training had no significant effect on pilots' experiences of SD.

All Illusions Combined

Analysis of all SD illusions combined revealed that FJ pilots reported significantly more SD than ME or TR pilots ($p<0.01$). Pilots who had received in-flight SD training reported more SD overall than those who had not received any in-flight training ($p < 0.01$). Total flying time and hours-on-type were positively associated with pilots' experience of all SD illusions combined ($p < 0.0001$).

Visual illusions

FJ pilots experienced more visual SD illusions than did TR or ME pilots ($p<0.001$ and $p<0.01$ respectively). There were more visual SD illusions experienced by pilots who had received in-flight training compared to those who had not ($p < 0.0001$). Total flying time and hours-on-type were positively associated with pilots' experience of all visual SD illusions combined ($p <0.0001$) while rating of training was negatively correlated with visual SD illusions ($p<0.05$), indicating that pilots who rated their training highest were least likely to report visual illusions.

Nonvisual Illusions

FJ pilots reported more nonvisual illusions than either RW pilots ($p < 0.01$) or ME pilots ($p<0.001$), and TR pilots reported more of these illusions than ME or RW pilots ($p<0.001$ and $p<0.01$ respectively). Pilots who had received in-flight training reported more nonvisual illusions than those who had not received in-flight training ($p < 0.0001$). Hours-on-type was positively correlated with experience of nonvisual SD illusions ($p < 0.0001$).

Miscellaneous SD

Pilots who received in-flight training reported more incidents of giant hand/detachment and SD associated with task saturation than pilots who had not received this training ($p<0.001$ and $p<0.0001$ respectively). In-flight training was not associated with SD arising from poor crew coordination. The linear covariate hours-on-type was positively associated with all of the miscellaneous SD (giant hand/detachment and task saturation $p<0.0001$, crew coordination $p<0.05$), while total flying hours was positively associated only with crew coordination ($p<0.001$). Age was negatively associated with pilots reporting giant hand/detachment illusions ($p<0.05$). Aircraft type was associated with crew coordination SD, with FJ pilots recording fewer incidents than pilots of all other aircraft types ($p<0.001$) and TR reporting less SD related to crew-coordination problems than ME or RW pilots ($p<0.001$). RW pilots reported more giant hand/detachment illusions than ME pilots ($p<0.01$), but there were no other significant effects of aircraft type.

Dependent Variables	Fixed Variables					
	Age	**Training - Rating**	**In-flight Training**	**Aircraft Type**	**Total Flying Hours**	**Hours on Type**
All Illusions			Given>Not Given****	FJ>TR**, ME**	+ve**	+ve****
Visual		-ve*	Given>Not Given****	FJ>TR***,ME**	+ve****	+ve****
Nonvisual			Given>Not Given****	FJ>RW** FJ>ME*** TR>ME*** TR>RW**		+ve****
Giant Hand/ Detachment	-ve*		Given>Not Given***	RW>ME**		+ve****
Task Saturation			Given>Not Given****			+ve****
Crew Coordination				ME>FJ*** ME>TR*** TR>FJ*** RW>FJ*** RW>TR***	+ve***	+ve*
Display – All	+ve****	-ve*	Given>Not Given****	RW> ME***,TR*** FJ>ME*** FJ>TR***	+ve****	
HUD	+ve****			FJ>RW*** FJ>ME*** FJ>TR***		
NVG			Given>Not Given*	RW>FJ*** RW>ME*** RW>TR*** ME>TR*** FJ>TR***		+ve****
Most Recent SD				RW>ME*, TR** FJ>ME*,TR**		
Worst SD		-ve**		RW>ME*** FJ>ME*** TR>ME**	+ve****	

Table 8. Summary of results from the statistical analysis of survey data (*p<0.05, **p<0.01, ***p<0.001, ****p<0.0001)

Display Related SD - All

FJ and RW pilots experienced more display-related SD than ME or TR pilots ($p<0.001$). Age and in-flight training were positively associated with display-related SD ($p<0.0001$), while rating of training was negatively associated with reports of display-related SD ($p<0.05$).

HUD Illusions

FJ pilots reported more HUD-related SD illusions than did ME, RW and TR pilots ($p<0.001$). Increasing age was positively associated with experience of HUD-related SD illusions ($p<0.0001$).

NVG Illusions

Aircraft type had a significant effect on the reported incidence of NVG-related SD. RW pilots reported more NVG-related SD than FJ, ME, and TR pilots ($p<0.001$). FJ and ME pilots also reported more NVG related SD than TR pilots ($p<0.001$). The linear covariate hours-on-type was positively associated with the reported incidence of NVG illusions ($p<0.0001$).

Severity of Pilots' Most Recent SD Incident

The severity of pilots' most recent SD incident was significantly higher in the FJ and RW groups than in the ME and TR groups (FJ and RW>ME – $p<0.05$, FJ and RW> TR – $p<0.01$).

Severity of the Pilots' Worst SD Incident

As with pilots' most recent SD incident, there was an effect of aircraft type. ME pilots' worst experience of SD was significantly less severe than that of all other pilots (RW – $p<0.001$, FJ – $p<0.001$, TR – $p<0.01$). Total flying hours was positively correlated with severity of the worst SD incident ($p<0.0001$), while rating of training was negatively correlated ($p<0.01$).

DISCUSSION

In order to achieve a high return rate on this postal survey, it was not possible to ask questions in as much detail as would have been possible with a researcher-administered questionnaire. Nonetheless, this survey obtained important basic information about SD training and type of SD experience in a wide variety of aircraft types.

Pilot experience was found to be a strong predictor for reporting SD incidents, with hours-on-type and total flying hours being positively associated with reports of SD. To some extent, this was because pilots with more experience had more opportunity to experience SD than their peers with fewer hours. However, experienced pilots also tended to report a higher frequency of each SD illusion, which was independent of the total number of aircraft sorties flown on type. This suggests that experienced pilots are better able to recognize specific types of SD than those with less flying experience. An alternative, though less likely, explanation would be that experienced pilots become disoriented more, perhaps as a result of taking more risks or flying more provocative maneuvers. If this were the case, one would expect to see a higher mishap rate among experienced pilots, but there does not appear to be a strong relationship between flying hours and SD incidents/mishaps[3-5,9,14,20]. The finding that age was positively associated with reports of display related SD (display-all and HUD related SD) is interesting and may indicate that older pilots have greater difficulty creating a mental model of where they are in space from primary flight reference symbology than young pilots.

Although, from this survey, pilots appear to be satisfied with the SD training they are receiving, previous SD surveys and mishap studies have not looked at the effects that type of training and satisfaction with training have on the incidence of SD in flight. In this survey, SD training using a variety of tools (lectures, ground-based devices and in-flight training) appeared to be better than didactic presentations alone, but only in-flight training had any significant positive relationship with pilots' experience of SD. This suggests that pilots who receive in-flight training are more likely to recognize, and be able to categorize, SD than their peers who have not had such training. However, the negative association between rating of training and some types of SD (visual, display-all and worst SD) is more difficult to explain if better training

improves SD recognition. One possible explanation could be that good training prevents certain types of SD from occurring in the first place.

Although in-flight training appears to help pilots recognize SD, USAF undergraduate pilot training curriculum does not currently include standardized demonstrations of SD in-flight, though in-flight unusual attitude recovery training is given. Furthermore, with the exception of those fortunate enough to have experienced SD training in the Advanced Spatial Disorientation Demonstrator, pilots' experiences of ground-based training have been limited to basic demonstrations in the Barany chair or the aging Vista Vertigon This lack of availability of realistic ground training may explain the fact that ground training did not have a significant effect on pilots' recognition of SD in this survey. Alternatively, the fact that ~ 80% of all pilots surveyed had received SD lectures and ground-based demonstrations may have limited the ability to discriminate statistically between those that received or did not receive such training. Unfortunately, this survey was unable to identify whether advanced ground based SD demonstrators, such as the USAF's Advanced Spatial Disorientation Demonstrator, are more effective at teaching pilots to recognize SD than basic rotational devices.

This survey has shown that different aircraft streams produce different SD challenges for pilots to overcome. Not surprisingly, FJ and RW pilots tended to report more SD than did ME and TR pilots. These differences are a result of a wide variety of factors including G-loading, typical sortie altitude, balance of night versus day flying, use of visual aids (e.g., NVGs), etc. RW pilots operate in a unique motion environment quite unlike that of fixed-wing aircraft, so it is not surprising that the illusions experienced by RW pilots are different. With further analysis it would be possible to identify specific problem areas for individual aircraft types and, armed with this information, it should be possible to refine SD training to focus on issues pertinent to aircrew flying these aircraft.

As aircraft become more agile and greater sensory demands are placed on pilots (HMDs, greater use of night vision devices, etc.), the incidence and severity of SD are likely to increase unless more effective countermeasures are introduced. Better training would undoubtedly help, but is unlikely to be enough in and of itself. More effective orientational symbology, whether presented visually (e.g., on HMDs) or non-visually (e.g., tactile vest and 3-D audio), may also help pilots maintain spatial orientation and aid in recognizing and recovering from unusual attitudes should pilots become disoriented. Ground collision avoidance systems also have a role to play in reducing the incidence of controlled flight into terrain. The questionnaire used in this survey could allow researchers to evaluate the effectiveness of these countermeasures by providing them with a standardized tool for data collection and comparison.

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